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(54) Signal to interference ratio estimation

(57) A circuit is designed with an estimate circuit (132) coupled to receive a plurality of predetermined signals (416-418) from an external source. Each of the predetermined signals is spaced apart in time. The estimate circuit produces a first estimate signal in response to at least one of the plurality of predetermined signals. An averaging circuit is coupled to receive a data signal (416) and at least one of the plurality of predetermined signals. The averaging circuit produces an average signal from the data signal and the at least one of the plurality of predetermined signals.

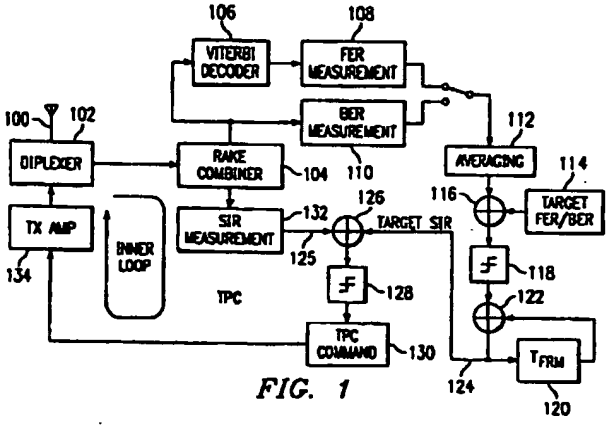

FIG. 1

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Description

FIELD OF THE INVENTION

[0001] This invention relates to wideband code division multiple access (WCDMA) for a communication system and more particularly to signal-to-interference ratio estimation of WCDMA signals.

BACKGROUND OF THE INVENTION

[0002] Present code division multiple access (CDMA) systems are characterized by simultaneous transmission of different data signals over a common channel by assigning each signal a unique code. This unique code is matched with a code of a selected receiver to determine the proper recipient of a data signal. These different data signals arrive at the receiver via multiple paths due to ground clutter and unpredictable signal reflection. Additive effects of these multiple data signals at the receiver may result in significant fading or variation in received signal strength. In general, this fading due to multiple data paths may be diminished by spreading the transmitted energy over a wide bandwidth. This wide bandwidth results in greatly reduced fading compared to narrow band transmission modes such as frequency division multiple access (FDMA) or time division multiple access (TDMA).

[0003] New standards are continually emerging for next generation wideband code division multiple access (WCDMA) communication systems as described in U.S Patent Application No.09/294,722 entitled "CDMA Mobile System and Method with Improved Channel Estimation and Pilot Symbol Transmission", filed 19th April 1999 and incorporated herein by reference. These WCDMA systems are coherent communications systems with pilot symbol assisted channel estimation schemes. These pilot symbols are transmitted as quadrature phase shift keyed (QPSK) known data in predetermined time frames to any receivers within range. The frames may propagate in a discontinuous transmission (DTX) mode. For voice traffic, transmission of user data occurs when the user speaks, but no data symbol transmission occurs when the user is silent. Similarly for packet data, the user data may be transmitted only when packets are ready to be sent. The frames are subdivided into sixteen equal time slots of 0.625 milliseconds each. Each time slot is further subdivided into equal symbol times. At a data rate of 32 thousand symbols per second (ksps), for example, each time slot includes twenty symbol times. Each frame includes pilot symbols as well as other control symbols such as transmit power control (TPC) symbols and rate information (RI) symbols. These control symbols include multiple bits otherwise known as chips to distinguish them from data bits. The chip transmission time (T_C), therefore, is equal to the symbol time rate (T) divided by the number of chips in the symbol (N).

[0004] Referring to FIG. 1, there is a simplified diagram of a mobile communication system. The mobile communication system includes an antenna 100 for transmitting and receiving external signals. The diplexer 102 controls the transmit and receive function of the antenna. Multiple fingers of rake combiner circuit 104 combine received signals from multiple paths. Symbols from the rake combiner circuit 104 are applied to a bit error rate (BER) circuit 110 and to a Viterbi decoder 106. Decoded symbols from the Viterbi decoder are applied to a frame error rate (FER) circuit 108. Averaging circuit 112 produces one of a FER and BER. This selected error rate is compared to a corresponding target error rate from reference circuit 114 by comparator circuit 116. The compared result is applied to bias circuit 120 via circuit 118 for generating a signal-to-interference ratio (SIR) reference signal on lead 124.

[0005] Pilot symbols from the rake combiner 104 are applied to the SIR measurement circuit 132. The SIR measurement circuit 132 produces a received signal strength indicator (RSSI) estimate from an average of received pilot symbols. The SIR measurement circuit also produces an interference signal strength indicator (ISSI) estimate from an average of interference signals from base stations and other mobile systems over many time slots. The SIR measurement circuit produces an SIR estimate from a ratio of the RSSI signal to the ISSI signal. This SIR estimate is compared with a target SIR by circuit 126. This comparison result is applied to TPC command circuit 130 via circuit 128. The TPC command circuit 130 sets a TPC symbol that is transmitted to a remote base station. This TPC symbol instructs the base station to either increase or decrease transmit power by preferably 1 dB for subsequent transmission.

[0006] The diagram of FIG. 2 illustrates the closed-loop transmit power control sequence between the base station and the mobile system. The base station receives a group of pilot symbols 200 in a time slot 204 from the mobile system. The base station determines an SIR ratio from the pilot symbols 200 and TPC symbol 202 and adjusts transmit power accordingly. This adjusted transmit power is applied to time slot 210 of downlink 220. The time slot 210 is offset from time slot 204 by one-half time slot or 0.3125 milliseconds, so the mobile system has time to adjust transmit power in response to TPC symbol 208 for the next time slot 218 of uplink 230. The mobile system determines an RSSI estimate from pilot symbols 206 of time slot 210. For high data-rate channels such as 256-1024 thousand symbols per second (ksps), there are preferably eight pilot symbols in each time slot. For low data-rate channels such as 32-128 ksps (FIG. 3) there are preferably four pilot symbols in each time slot. The ISSI estimate includes an average of interference signals over many time slots. The ISSI estimate, therefore, is relatively stable and changes slowly with time. By way of comparison, an RSSI estimate for time slot 310 may include an average of pilot symbols 308 alone. This small sample

produces large variations in the RSSI estimate. For example, for six fingers of rake combiner circuit 104, the RSSI estimate $\hat{S}_m$ for the m^{th} time slot is given by equation [1]. Here, $r_{k,m,g}$ corresponds to the k^{th} pilot symbol of the m^{th} time slot and the g^{th} finger with the pilot symbol data removed.

$$\hat{S}_m = \frac{1}{16}\sum_{g=1}^{6}\left(\left|\sum_{k=1}^{4} r_{k,m,g}\right|^2\right) \quad [1]$$

This RSSI estimate may fluctuate abruptly due to the limited number of pilot symbols available for averaging. The SIR estimate is given by equation [2], where $\hat{I}_m$ is the ISSI estimate for the m^{th} time slot, which is obtained by averaging the interference from many previous time slots. Since the SIR estimate is a ratio of the RSSI to the ISSI estimate, most of the variation of the SIR estimate is due to the RSSI variation. The variation in the SIR estimate produces erratic TPC control and correspondingly large variations in transmit power.

$$\hat{SIR}_m = \frac{\hat{S}_m}{\hat{I}_m} \quad [2]$$

These large variations in transmit power degrade communications between the base station and the mobile system.

SUMMARY OF THE INVENTION

[0007] These problems are resolved by a circuit comprising an estimate circuit coupled to receive a plurality of predetermined signals from an external source. Each of the predetermined signals is spaced apart in time. The estimate circuit produces a first estimate signal in response to at least one of the plurality of predetermined signals. An averaging circuit is coupled to receive a data signal and at least one of the plurality of predetermined signals. The averaging circuit produces an average signal from the data signal and at least one of the plurality of predetermined signals.

[0008] The present invention improves signal-to-interference estimation by averaging pilot symbols and corrected data symbols. Closed-loop power control is improved. A standard deviation of transmit power is greatly reduced, and the link margin of the system is improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The present invention will now be further described by way of example, with reference to certain exemplary embodiments illustrated with reference to the accompanying drawings in which:

FIG. 1 is a block diagram of a mobile communications system;

FIG. 2 is a diagram showing a transmit power control sequence of the prior art;

FIG. 3 is a diagram showing pilot symbols used for received signal strength estimation of the prior art;

FIG. 4 is a diagram showing pilot symbols used for received signal strength estimation according to an embodiment of the present invention;

FIG. 5A is a diagram showing a first iteration of signal-to-interference ratio determination according to an embodiment of the present invention;

FIG. 5B is a diagram showing a second iteration of signal-to-interference ratio determination according to an embodiment of the present invention;

FIG. 6A is a simulation result of RMS error for the RSSI estimate according to an embodiment of the present invention; and

FIG. 6B is a simulation result of standard deviation of a closed-loop power control system according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0010] Referring to FIG. 4, there is a diagram showing pilot symbols used for received signal strength indicator (RSSI) estimation in accordance with an embodiment of the present invention. The SIR measurement circuit 132 (FIG. 1) is designed to sample groups of pilot symbols (416-418) from three consecutive time slots (400-404) having an exemplary data rate of 64 ksps with forty symbols in each time slot. These pilot symbols are predetermined signals having a known value. Averaging circuit 412 produces an average of these predetermined symbols to produce an improved channel estimate of phase and magnitude of received data signals. This improved channel estimate is then used by a correction or demodulation circuit to correct the first twelve data symbols 420 of the current time slot 404. The logical state of these twelve corrected data symbols is then known and they are used as virtual pilot symbols. An estimate circuit included in SIR measurement circuit 132 then averages pilot symbols 418 together with virtual pilot symbols or corrected data symbols 420 of the current frame 404 and produces an RSSI estimate signal according to equation [3].

$$\hat{S}_m = \frac{1}{256}\sum_{g=1}^{6}\left(\left|\sum_{k=1}^{16} r_{k,m,g}\right|^2\right) \quad [3]$$

This new RSSI estimate of equation [3] is highly advantageous in comparison to the estimate of equation [1] of the prior art. An average of pilot symbols in the current time slot together with pilot symbols from the two previous time slots determines the improved channel esti-

mate. The improved channel estimate is used to create virtual pilot symbols 420 from data symbols in the current time slot. The RSSI estimate, therefore, is an average of the sixteen most recent symbols of the current time slot, including four pilot symbols 418 and twelve virtual pilot symbols 420. By way of comparison with equation [1] of the prior art, the RSSI estimate of equation [3] with six rake fingers is an average of sixteen. This increase in symbols by a factor of four produces a more stable RSSI estimate with a smaller variance over time. Thus, closed-loop transmit power is more closely regulated between the base station and the mobile communication system.

[0011] The SIR measurement circuit 132 produces an SIR signal on lead 125 (FIG. 1) in response to the new RSSI and the ISSI. A comparison circuit 126 compares the SIR signal to a target SIR on lead 124. A result of the comparison is applied to TPC command circuit 130 via circuit 128. The TPC command circuit then applies an appropriate TPC symbol to transmit amplifier 134 for inclusion in the next transmit time slot. This TPC symbol instructs a remote base station to preferably increase or decrease transmit power by 1 dB.

[0012] Turning now to FIG. 5A, there is a diagram of a first iteration of an iterative signal-to-interference ratio determination according to an embodiment of the present invention. Averaging circuit 412 receives three groups of four pilot symbols 416-418 from the current time slot 404 and the prior time slots (400-402). The averaging circuit produces an improved initial channel estimate from the predetermined state of these twelve pilot symbols. The correction or demodulation circuit then uses this improved channel estimate to correct phase and magnitude of thirty-six data symbols 500 from time slot 402 as well as twelve data symbols from time slot 404. These corrected data symbols yield forty-eight virtual pilot symbols 500 and 420. In a second iteration of the an iterative signal-to-interference ratio determination (FIG. 5B), averaging circuit 412 produces a second channel estimate from pilot symbols 417-418 and virtual pilot symbols 500 and 420. The correction circuit then uses the second channel estimate to correct data symbols 420 of frame 404. An iterative RSSI is then determined from an average of pilot symbols 418 and corrected data symbols 420. This iterative RSSI provides a further improvement of the channel estimate used to correct data symbols of the current time slot 404. This improved channel estimate further improves the RSSI and subsequent SIR estimate. The SIR estimate, therefore, provides more stable closed-loop transmit power control between the remote base station and the mobile communication system.

[0013] Referring now to FIG. 6A, there is a simulation result of root-mean-square (RMS) error for the RSSI estimate according to an embodiment of the present invention. The RSSI estimate corresponds to a Rayleigh channel with four paths and an 80 Hz Doppler rate. The family of curves includes an upper dashed curve corresponding to RSSI estimation of the prior art for four pilot symbols. A lower dashed curve for sixteen pilot symbols is included as a theoretical minimum error for comparison with simulations according to an embodiment of the present invention. The RSSI estimates of the present invention include intermediate curves for one, two and four pilot symbols and for one and two iterations. The RSSI estimate of the present invention produces a smaller RMS error than four pilot symbol estimates of the prior art over the entire SIR range. Furthermore, iterative RSSI estimates for one and two pilot symbols have only a slightly greater RMS error than iterative four pilot symbol estimates of the present invention. Thus, the iterative RSSI estimation provides sufficient improvement to reduce pilot symbol overhead in each time slot without compromise to SIR estimation.

[0014] Turning now to FIG. 6B, there is a simulation result comparing a standard deviation of closed-loop power control for three Doppler rates. The upper curve shows a significantly greater standard deviation in transmit power for all Doppler rates than with iterative RSSI estimates according to an embodiment of the present invention. In particular, the standard deviation for a 5 Hz Doppler rate is reduced by half from 3 dB to less than 1.5 dB. Furthermore, as in the previous simulation, the standard deviation is substantially the sane for one, two or four pilot symbols in each time slot.

[0015] Although the present invention has been described in detail with reference to a preferred embodiment thereof, it is to be understood that this description is by way of example only and is not to be construed in a limiting sense. For example, the iterative RSSI estimation of an embodiment of the present invention may be extended to more than two iterations. Moreover, virtual pilot symbols may include a single data symbol, a rate information symbol or any other symbols that are corrected for phase and frequency. Furthermore, another embodiment of the present invention includes a user identification symbol (UDI) for each time slot. This UDI symbol indicates a presence or absence of data within a time slot. For example, during voice transmission time slots corresponding to a pause in speaking would have no data symbols. Such an indication by the UDI symbol instructs circuits of the present invention to rely on pilot symbols alone for Rayleigh fading parameter estimates and SIR estimates.

[0016] It is understood that the inventive concept of the present invention may be embodied in a mobile communication system as well as circuits within the mobile communication system. It is to be further understood that numerous changes in the details of the embodiments of the invention will be apparent to persons of ordinary skill in the art having reference to this description.

Claims

1. A circuit, comprising:

an estimate circuit coupled for receiving a plurality of predetermined signals from an external source, each of the predetermined signals being spaced apart in time, and for producing a first estimate signal in response to at least one of the plurality of predetermined signals; and

an averaging circuit coupled for receiving a data signal and at least one of the plurality of predetermined signals, for producing an average signal from the data signal and said at least one predetermined signal.

2. A circuit as in claim 1, wherein each of said plurality of predetermined signals comprises a group of pilot symbols, each group of pilot symbols corresponding to a respective time slot.

3. A circuit as in claim 2, further comprising:

a combiner circuit coupled for receiving a first group of pilot symbols at a first time and for receiving the first group of pilot symbols at a second time, the combiner circuit arranged for producing an average of the first group received at the first time and the first group received at the second time.

4. A circuit as in any preceding claim, wherein the data signal comprises a plurality of data symbols.

5. A circuit as in any preceding claim, further comprising:

a comparison circuit coupled for receiving the estimate signal and a reference signal, the comparison circuit arranged for producing a control signal in response to the estimate signal and the reference signal.

6. A circuit as in one of claims 1-4, wherein the estimate circuit is further coupled for receiving the average signal, and the estimate circuit is arranged for producing a second estimate signal in response to the average signal.

7. A circuit as in claim 6, wherein the averaging circuit is coupled for receiving the second estimate signal, and for producing a second average signal of the data signal and said at least one of the predetermined signals in response to the second estimate signal.

8. A circuit as in claim 7, wherein the plurality of predetermined signals are wideband code division multiple access signals received in a transmitted frame and wherein each predetermined signal corresponds to a respective time slot.

9. A circuit as in claim 8, wherein each predetermined signal comprises a plurality of pilot symbols.

10. A circuit as in claim 8, wherein the estimate circuit and the averaging circuit are formed on a single integrated circuit.

11. A circuit as in any of claims 6-10, wherein the first estimate signal and the second estimate signal are Rayleigh fading parameter estimate signals.

12. A circuit as in any one of claims 1-4, and claims 7-10, further coupled for receiving a UDI symbol, wherein the averaging circuit is arranged for producing the average signal from said at least one of the plurality of predetermined signals and not the data signal in response to the UDI symbol.

13. A circuit, comprising:

a correction circuit coupled for receiving a data signal and a first estimate signal, and arranged for producing a corrected data signal in response to the first estimate signal;

and an estimate circuit coupled for receiving a plurality of predetermined signals and the corrected data signal, and for producing a second estimate signal in response to at least one of the plurality of predetermined signals and the corrected data signal.

14. A circuit as in claim 13, further comprising:

a comparison circuit coupled for receiving the second estimate signal and a reference signal, and for producing a control signal in response to the second estimate signal and the reference signal.

15. A circuit as in claims 13 or 14, wherein the second estimate signal is a signal-to-interference ratio signal, the reference signal is a signal-to-interference reference signal and the control signal is a transmit power control symbol.

16. A circuit as in claim 13 or 14, wherein each of the first and second estimate signals are channel estimate signals and wherein the correction circuit is further coupled for receiving the second estimate signal, the correction circuit is arranged for producing a second corrected data signal in response to the second estimate signal.

17. A circuit as in claim 16, wherein the estimate circuit is arranged for producing a signal-to-interference ratio signal in response to the second corrected data signal and wherein a comparison circuit is arranged for producing a transmit power control

symbol in response to the signal-to-interference ratio signal and a reference signal.

18. A circuit as in any of claims 13, 14, or 16, wherein the data signal comprises a plurality of data symbols.

19. A circuit as in any of claims 13, 14, or 16, wherein the corrected data signal comprises a plurality of demodulated QPSK data signals.

20. A circuit as in claim 19, wherein each predetermined signal of the plurality of predetermined signals comprises a group of pilot symbols, each group of pilot symbols corresponding to a respective time slot.

21. A method of processing signals in a communication circuit, comprising the steps of:

receiving a first plurality of groups of predetermined signals from an external source, each group of the first plurality of groups being equally spaced apart from another group in time;
receiving a data signal; and
producing a first average of at least one of the first plurality of groups and the data signal.

22. A method of processing signals as in claim 21, further comprising the steps of:

receiving a second plurality of groups of predetermined signals from a plurality of external sources; and
producing a second average of at least one of the second plurality of groups; and
producing a signal-to-interference ratio signal in response to the first average and the second average.

23. A method of processing signals as in claim 22, further comprising the step of:

determining a signal-to-interference ratio signal from the first and second averages.

24. A method of processing signals as in any one of claims 21-23, further comprising the steps of:

producing an estimate signal from the first average;
correcting the data signal in response to the estimate signal; and
producing a second average of said at least one of the first plurality of groups and the data signal.

25. A method of processing signals as in claim 21, wherein each group of the first plurality of groups is a group of pilot symbols in a respective time slot.

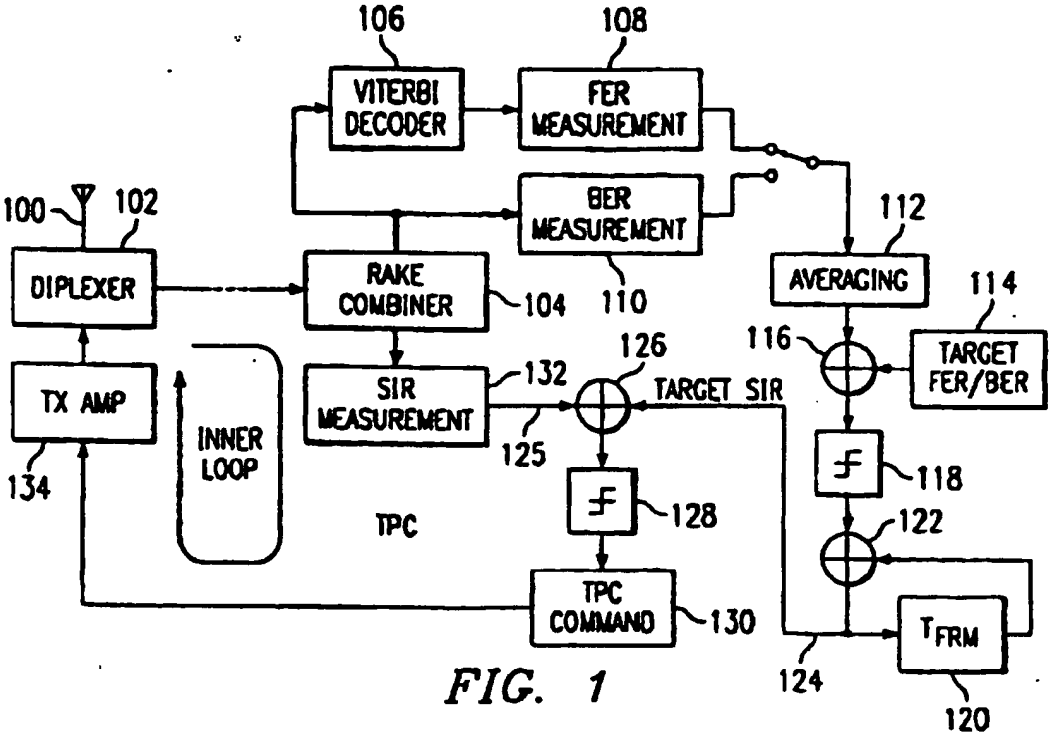

FIG. 1

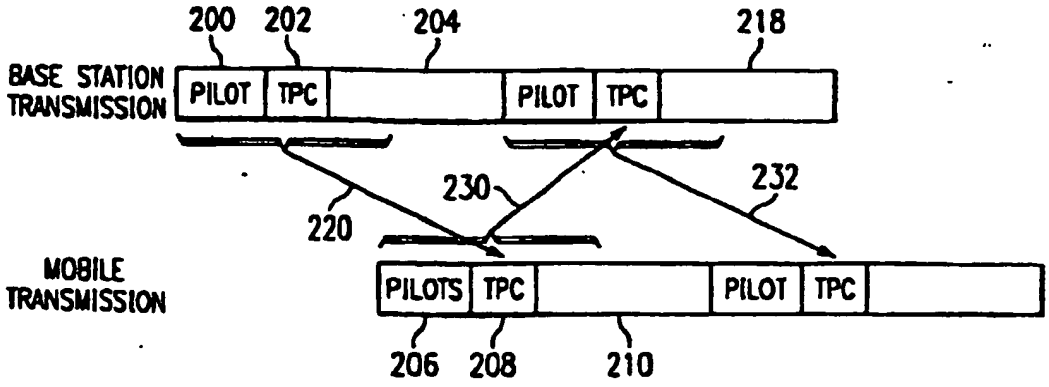

FIG. 2
(PRIOR ART)

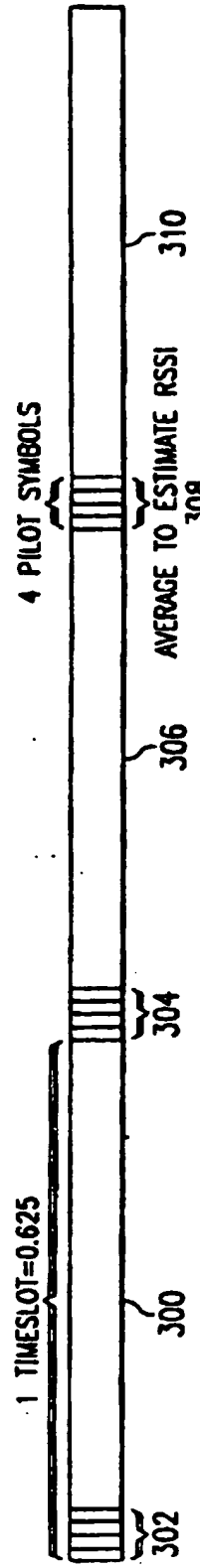

FIG. 3
(PRIOR ART)

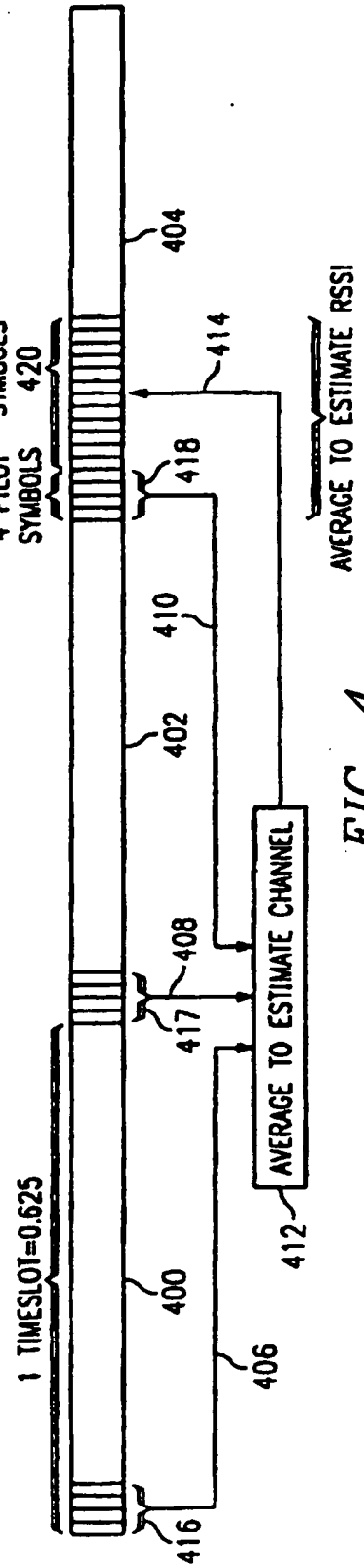

FIG. 4

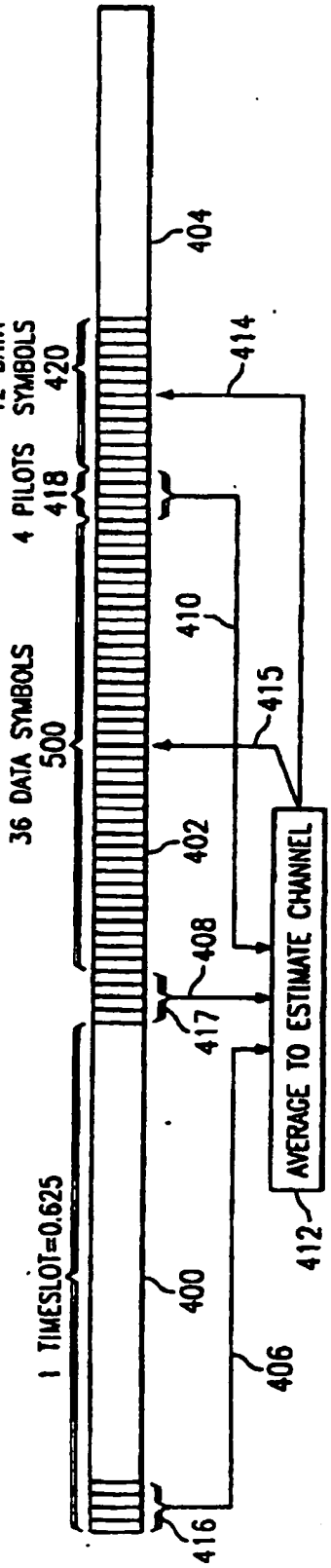
1 TIMESLOT=0.625
400
406
416
36 DATA SYMBOLS
500
4 PILOTS
418
12 DATA SYMBOLS
420
404
414
410
415
402
408
417
AVERAGE TO ESTIMATE CHANNEL
412

FIG. 5A

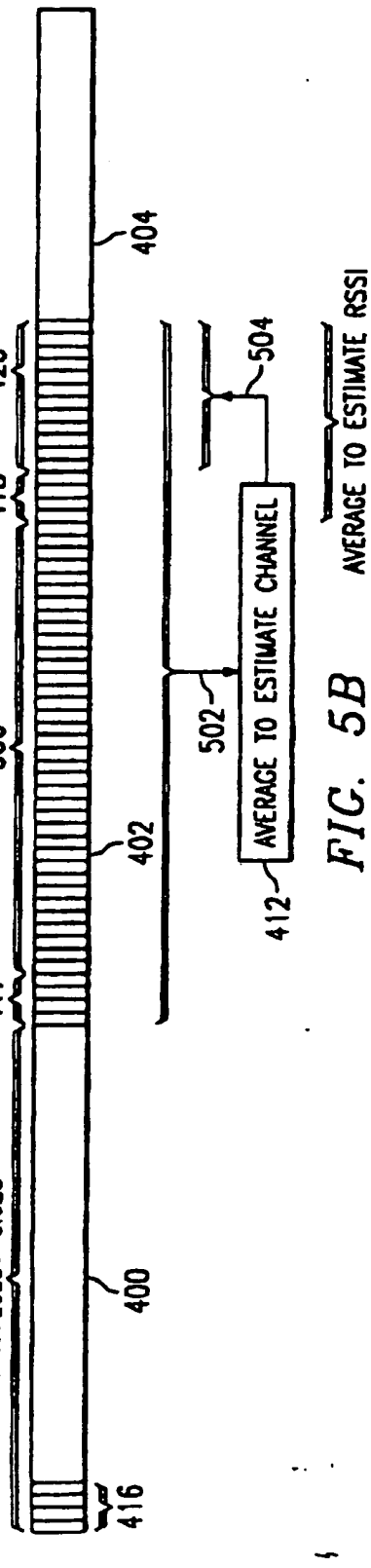
1 TIMESLOT=0.625
400
416
36 DATA SYMBOLS
500
4 PILOTS
418
12 DATA SYMBOLS
420
404
402
417
502
504
AVERAGE TO ESTIMATE CHANNEL
412
AVERAGE TO ESTIMATE RSSI

FIG. 5B

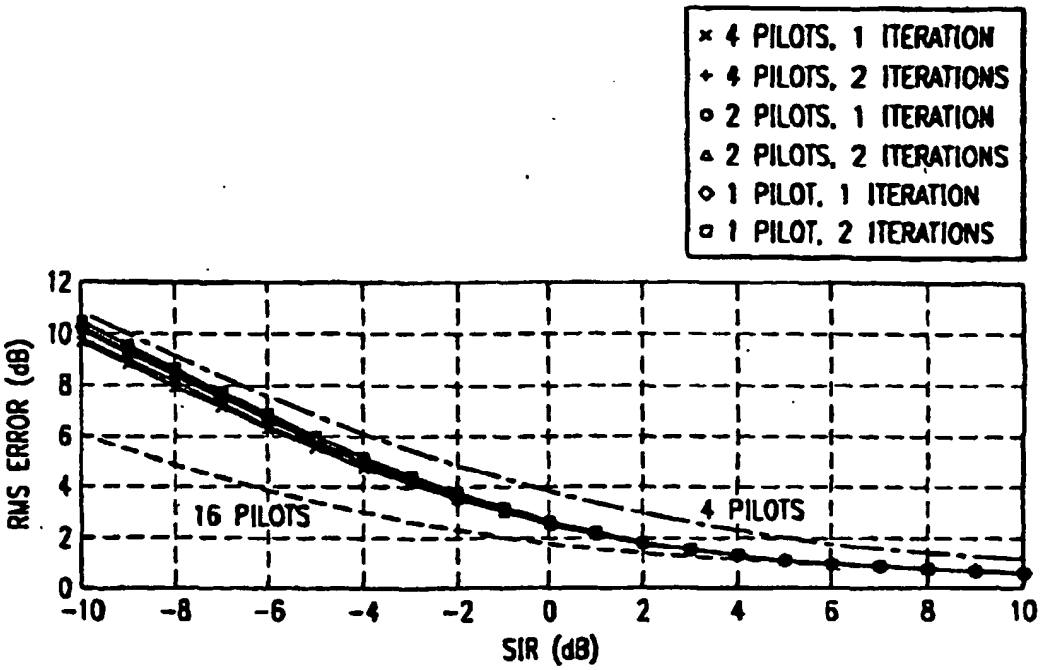
× 4 PILOTS, 1 ITERATION
+ 4 PILOTS, 2 ITERATIONS
o 2 PILOTS, 1 ITERATION
△ 2 PILOTS, 2 ITERATIONS
◇ 1 PILOT, 1 ITERATION
□ 1 PILOT, 2 ITERATIONS
RMS ERROR (dB)
SIR (dB)
16 PILOTS
4 PILOTS
12
10
8
6
4
2
0
-10
-8
-6
-4
-2
0
2
4
6
8
10

FIG. 6A

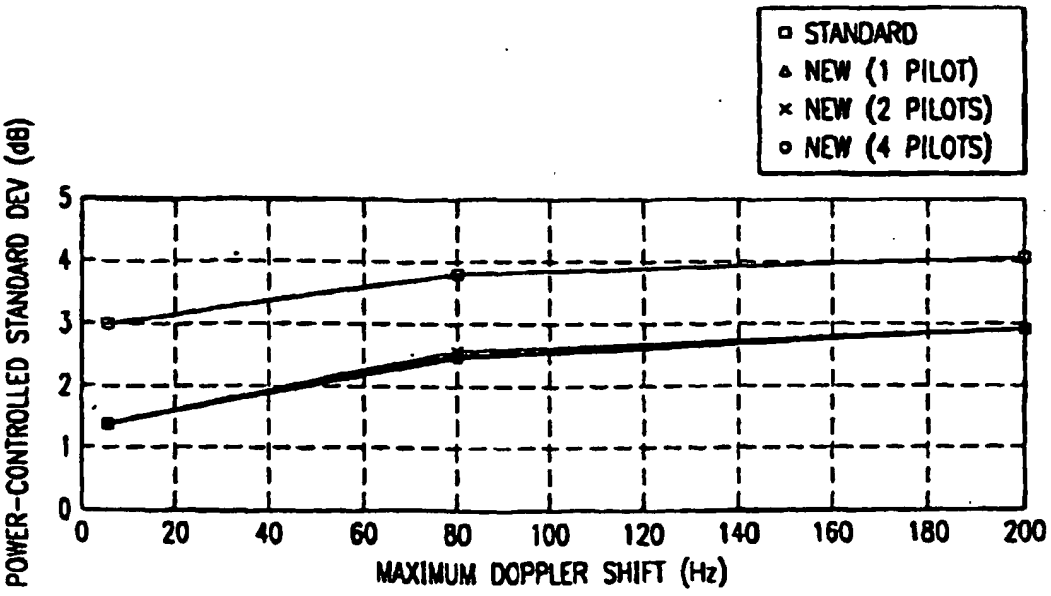
□ STANDARD
△ NEW (1 PILOT)
× NEW (2 PILOTS)
o NEW (4 PILOTS)
POWER-CONTROLLED STANDARD DEV (dB)
MAXIMUM DOPPLER SHIFT (Hz)
5
4
3
2
1
0
0
20
40
60
80
100
120
140
160
180
200

FIG. 6B

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